

C. McClain  
970.2

## **Final Report**

Performance Period 12/1/00-11/30/03

### **Bio-optical measurement and modeling of the California Current and Southern Oceans**

**B. Greg Mitchell, Principal Investigator**

Scripps Institution of Oceanography

University of California San Diego

La Jolla, CA 92093-0218

Email: [gmitchell@ucsd.edu](mailto:gmitchell@ucsd.edu)

Phone: (858) 534-2687

Contract number: NAS5-01002

## TABLE OF CONTENTS

<b>YEAR END TECHNICAL MEMORANDUM 2003 .....</b>	<b>3</b>
<i>INTRODUCTION.....</i>	3
<i>RESEARCH METHODS AND DATA .....</i>	3
<i>RESEARCH RESULTS.....</i>	4
<i>FUTURE PLANS.....</i>	5
<i>REFERENCES.....</i>	5
<i>FIGURE CAPTIONS.....</i>	6
<b>YEAR END TECHNICAL MEMORANDUM 2002 .....</b>	<b>10</b>
<i>INTRODUCTION.....</i>	10
<i>RESEARCH METHODS AND DATA .....</i>	10
<i>RESEARCH RESULTS.....</i>	11
<i>FUTURE PLANS.....</i>	12
<i>REFERENCES.....</i>	13
<b>YEAR END TECHNICAL MEMORANDUM 2001 .....</b>	<b>19</b>
<i>INTRODUCTION.....</i>	19
<i>RESEARCH METHODS AND DATA .....</i>	19
<i>RESEARCH RESULTS.....</i>	20
<i>FUTURE PLANS.....</i>	21
<i>REFERENCES.....</i>	21

# **Year End Technical Memorandum 2003**

## **Bio-optical measurement and modeling of the California Current and Southern Oceans**

B. Greg Mitchell, Principal Investigator

Scripps Institution of Oceanography

University of California San Diego

La Jolla, CA 92093-0218

Email: gtmitchell@ucsd.edu, Phone: (858) 534-2687

Contract number: NAS5-01002

### ***Introduction***

This SIMBIOS project contract has supported *in situ* ocean optical observations in the California Current, and in the north Pacific, Southern and Indian Oceans. Our principal goals are to validate standard or experimental ocean color products through detailed bio-optical and biogeochemical measurements, and to combine ocean optical observations with modeling to contribute to satellite vicarious radiometric calibration and algorithm development. In collaboration with major oceanographic ship-based observation programs (CalCOFI, JGOFS, AMLR, INDOEX, and ACE Asia) our SIMBIOS effort has resulted in data from diverse bio-optical provinces. For these global deployments we generate a methodologically consistent data set encompassing a wide-range of oceanic conditions. We have initiated several collaborations with scientists in East Asian countries to study the complex Case-2 waters of their marginal seas. Global data collected in recent years are routinely evaluated relative to our CalCOFI time-series. The combined database we have assembled now comprises more than 1000 stations and includes observations for the clearest oligotrophic waters, highly eutrophic blooms, red-tides and coastal Case-2 conditions. The data has been used to validate water-leaving radiance estimated with OCTS, SeaWiFS, MODIS and GLI as well as bio-optical algorithms for chlorophyll pigments. During the past year we continued to process and quality control our data and carried out a detailed calibration/validation exercise in the California Current for the Japanese GLI instrument. For this GLI initialization effort, we coordinated with the Mexico IMECOCAL program to get extra data to complement our CalCOFI data for the simultaneous April, 2003 cruises. The comprehensive data is utilized for development of standard and experimental algorithms.

### ***Research Methods and Data***

We continue to participate on CalCOFI cruises to the California Current System (CCS) for which we have an 8-year time-series. This region experiences a large dynamic range of coastal and open ocean trophic structure and has experienced strong interannual forcing associated with the El Niño – La Niña cycle from 1997-2000 (Kahru and Mitchell, 2000; Kahru and Mitchell, 2002). CalCOFI data provide an excellent reference for evaluating our other global data sets (O'Reilly et al. 1998; Mitchell et al. 2002b, 2002c). During the third year of our contract, we participated in 2 CalCOFI cruises, a cruise to the Southern Ocean (AMLR), and received data from colleagues in Korea and Hong Kong for East Asian coastal cruises. The April 2003 CalCOFI cruise (CAL0304) was coordinated with the simultaneous IMECOCAL cruise (IME0304) off Mexico. The combined April data are being used for a comprehensive campaign for calibration and validation of GLI algorithms. A preliminary analysis of the water-leaving radiances and fluorometric chlorophyll concentration was presented at the SPIE 2003 conference (Fukushima et al., 2003) and at the subsequent meeting at Scripps Institution of Oceanography on August 7, 2003. Work on the GLI calibration/validation using the combined dataset is continued.

The global distribution of our data collected during 6 years of SIMBIOS funding is shown in Figure 1. On most cruises, an integrated underwater profiling system was used to collect optical data and to characterize the water column. The system included an underwater radiometer (Biospherical Instruments MER-2040 or MER-2048) measuring depth, downwelling spectral irradiance ( $E_d$ ) and upwelling radiance ( $L_u$ ) in 13 spectral bands. A MER-2041 deck-mounted reference radiometer (Biospherical Instruments) provided simultaneous measurements of

above-surface downwelling irradiance. Details of the profiling procedures, characterization and calibration of the radiometers, data processing and quality control are described in Mitchell and Kahru (1998). The underwater radiometer was also interfaced with 25 cm transmissometers (SeaTech or WetLabs), a fluorometer, and SeaBird conductivity and temperature probes. When available, additional instrumentation integrated onto the profiling package included AC9 absorption and attenuation meters (WetLabs Inc.), and a Hydroscat-6 backscattering meter (HobiLabs). For two AMLR, ACE Asia and recent CalCOFI cruises we deployed our new Biospherical Instruments PRR-800 freefall radiometer that included 19 channels of surface irradiance (312-865 nm) and three geometries of underwater radiometry ( $L_u$ ,  $E_u$ ,  $E_d$ ) from 312 to 700 nm. We have shown that measuring these three radiometric geometries with our MER 2048 allowed us to retrieve backscatter and absorption coefficients (Stramska et al., 2000). Our colleagues in Hong Kong and Korea use PRR-800 profilers and collect samples for chlorophyll and absorption with methods consistent with ours. At *in situ* optical stations discrete water samples were collected from a CTD-Rosette immediately before or after each profile for additional optical and biogeochemical analyses. Pigment concentrations were determined fluorometrically and with HPLC. All HPLC samples acquired in the past year have been submitted to San Diego State University for analysis under a separate SIMBIOS contract. Spectral absorption coefficients (300-800 nm) of particulate material were estimated by scanning particles concentrated onto Whatman GF/F filters (Mitchell, 1990) in a dual-beam spectrophotometer (Varian Cary 1). Absorption of soluble material was measured in 10 cm cuvettes after filtering seawater samples through 0.2  $\mu$ m pore size polycarbonate filters. Absorption methods are described in more detail in Mitchell et al. (2002a). For some cruises we collected measurements of other optical and phytoplankton properties including photosynthesis, particulate organic matter (carbon and nitrogen), phycoerythrin pigment, and size distribution using flow cytometry and a Coulter Multi-sizer.

For most of our field work in association with CalCOFI and AMLR we submit all data directly to NASA SIMBIOS including supporting CTD and water bottle information. For the collaborations with Asian colleagues, we process their optical data and with their permission we will submit some of the Asian data to SIMBIOS in 2003. On the SOFEX cruise to the Southern Ocean we did not deploy a profiling radiometer, but we collected data for particle absorption; other SOFEX PIs collected samples for fluorometric chlorophyll and HPLC pigments. Our absorption data from SOFEX will be submitted to SIMBIOS and we will request approval to submit the pigment data.

## Research Results

Remote sensing reflectance ( $R_{rs}$ ) derived from the in-water measurements, defined as the ratio of upwelling radiance ( $L_u$ ) and downwelling irradiance ( $E_d$ ), is closely related to the normalized water-leaving radiance ( $L_{wn}$ ) product of satellite ocean color data.  $R_{rs}(\lambda)$  in Case-1 waters is well correlated to chl-a. As chl-a increases,  $R_{rs}$  generally decreases for SeaWiFS wavelengths 412, 443, 490, 510 nm due to increased absorption, but increases at SeaWiFS wavelength 555 and 665 nm due to increased backscatter [Mitchell and Kahru, 1998; O'Reilly et al., 1998]. To explore issues with Case-2 waters we have collaborated with colleagues in Korea (NFRDI), and Hong Kong (HKUST) to assemble a large regional data set from the East China Sea, South China Sea and coastal waters of Eastern Asia. Relationships between  $R_{rs}$  and chl-a for HKUST and NFRDI data can be both lower and higher than the Case-1 (CalCOFI) relationships, depending on whether absorption or scattering is the dominant process (data not shown).

Typical ocean color algorithms take ratios of reflectance for different spectral bands. The standard SeaWiFS chl-a algorithm is currently OC4v4 [O'Reilly et al., 1998; O'Reilly et al., 2000]. CalCOFI data set is a good reference data set since it covers a large range of chl-a, was acquired with very consistent methodology, and comprises approximately 25% of the data used for development of the SeaWiFS OC4v4 algorithm (O'Reilly et al., 2000). Kahru and Mitchell (1999; 2001) have shown that the chl-a retrieved by satellite in the CalCOFI region is in good agreement with our ship data when computed with our regional algorithm or NASA's OC4v4. Thus the CalCOFI region is an ideal location to evaluate new ocean color missions. We collaborated closely with Japanese colleagues and NASDA to execute a comprehensive calibration and validation program for GLI on the April CalCOFI and IMECOCAL cruises. The GLI empirical chlorophyll algorithm OC4-GLI (Mitchell and Kahru, unpublished) that uses the same maximum band ratio algorithm as OC4v4 of SeaWiFS (O'Reilly et al., 1998) but a different set of bands (443, 460, 520, 545 nm) seems to be working very well (Figure 2). The ratio of GLI-detected chlorophyll to SeaWiFS-detected chlorophyll (not shown) is close to one. The GLI water-leaving radiances correspond well to *in situ* measurements (Figure 2), especially considering the early phase of the cal/val process.

However, we are still seeing significant discrepancies between satellite-derived nLw and in situ values at near-shore CalCOFI stations (Figure 3). While the negative water-leaving radiances have disappeared in our match-ups, the SeaWiFS-derived nLw412 and even nLw443 are still often lower than in situ values. The maximum band ratio algorithms compensate for the decreased nLw values at 412 and 443 nm by switching to longer wavelength bands but the distortion in the satellite-derived nLw spectra causes severe problems for semi-analytic algorithms.

### ***Future Plans***

Since this is the final year of NASA SIMBIOS, NASA should define an explicit program for in situ support of ocean color satellites. Even for Case 1 waters, algorithm problems persist and this will be the focus of a session at the ASLO Ocean Sciences meeting in 2004. Our SIMBIOS data have demonstrated that the Southern Ocean should continue to be a high priority since it is evident that standard algorithms for chl-a do not perform well in this region (Mitchell and Holm-Hansen, 1991; Mitchell, 1992; Mitchell et al., 2002b; Reynolds et al., 2001). Furthermore, it is essential to broaden the in situ data sets to include detailed information on spectral absorption and backscattering, particle size distributions, mineral and organic mass, and the optical differentiation of bio-geochemically important taxa like diazotrophs, diatoms and coccolithophores. To understand the details of how community structure regulates spectral reflectance so that advanced algorithms can be developed requires a commitment to supporting detailed in situ studies.

### ***References***

- Carder, K.L., F.R. Chen, Z.P. Lee and S.K. Hawes (1999) Semianalytic moderate-resolution imaging spectrometer algorithms for chlorophyll a and absorption with bio-optical domains based on nitrate-depletion temperatures. *Journal of Geophysical Research*. 104(C3): 5,403-5,421
- Fukushima, H., M. Toratani, A. Tanaka, W.-Z. Chen, H. Murakami, R. Frouin, G. Mitchell and M. Kahru (2003) ADEOS-II/GLI ocean color atmospheric correction: early phase results. SPIE 48th Annual Meeting, San Diego, August 5, 2003.
- Garver, S.A. and D.A. Siegel (1997) Inherent Optical Property Inversion of Ocean Color Spectra and its Biogeochemical Interpretation: 1. Time series from the Sargasso Sea. *Journal of Geophysical Research*. 102(C8): 18,607-18,625
- Kahru, M. and B.G. Mitchell (1999) Empirical chlorophyll algorithm and preliminary SeaWiFS validation for the California Current. *International Journal of Remote Sensing*. 20(17): 3,423-3,430
- Kahru, M. and B.G. Mitchell (2000) Influence of the 1997-98 El Niño on the surface chlorophyll in the California Current. *Geophysical Research Letters*. 27(18): 2,937-2,940
- Kahru, M. and B.G. Mitchell (2001) Seasonal and non-seasonal variability of satellite-derived chlorophyll and colored dissolved organic matter concentration in the California Current. *Journal of Geophysical Research*. 106(C2): 2517-2529
- Kahru, M., B.G. Mitchell, J. Wieland, J.C. Chen, N.W. Man, Y.S. Suh, M. Stramska, and D. Stramski (2002) Evaluation of Satellite Ocean Color Algorithms for East Asian Marginal Seas. ASLO, Honolulu, Hawaii, February 2002.
- Kahru, M. and B.G. Mitchell (2002) Influence of El Niño – La Niña cycle on satellite-derived primary production in the California current. *Geophysical Research Letters*, 29(9), doi: 10.1029/2002GL014963
- Li, L.-P., H. Fukushima, R. Frouin, B.G. Mitchell, M. -X. He, I. Uno, T. Takamura, and S. Ohta (In Press) Influence of sub-micron absorptive aerosol on SeaWiFS-derived marine reflectance during ACE-Asia. *Journal of Geophysical Research – Atmospheres*.
- Loisel, H., D. Stramski, B.G. Mitchell, F. Fell, V. Fournier-Sicre, B. Lemasle, and M. Babin. (2001) Comparison of the ocean inherent optical properties obtained from measurements and inverse modeling. *Applied Optics*. 40(15): 2384-2397
- Mitchell, B.G. (1990) Algorithms for determining the absorption coefficient of aquatic particulates using the quantitative filter technique (QFT). In: Spinrad, R., ed., *Ocean Optics X*, Bellingham, Washington, SPIE, pp. 137-148
- Mitchell, B.G. (1992) Predictive bio-optical relationships for polar oceans and marginal ice zones. *Journal of Marine Systems*. 3: 91-105

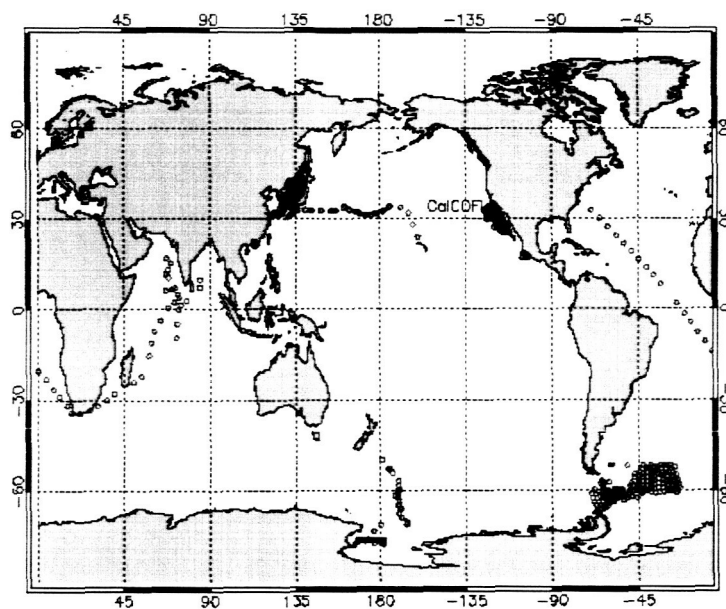
- Mitchell, B.G. and M. Kahru (1998) Algorithms for SeaWiFS standard products developed with the CalCOFI bio-optical data set. *Cal. Coop. Ocean. Fish. Invest. R.* 39: 133-147
- Mitchell, B.G. and O. Holm-Hansen (1991) Bio-optical properties of Antarctic Peninsula waters: Differentiation from temperate ocean models. *Deep-Sea Research I.* 38(8/9): 1,009-1,028
- Mitchell B. G., M. Kahru, J. Wieland and M. Stramska (2002a) Determination of spectral absorption coefficients of particles, dissolved material and phytoplankton for discrete water samples. In: Fargion, G.S. and J.L. Mueller, Eds. *Ocean Optics Protocols for Satellite Ocean Color Sensor Validation*, NASA Technical Memorandum 2002-210004/Rev 3-Vol 2, Chapter 15, P. 231-257.
- Mitchell, B.G., M. Kahru, R. Reynolds, J. Wieland, D. Stramski, C. Hewes, and O. Holm-Hansen (2002b) Chlorophyll-a Ocean Color Algorithms for the Southern Ocean and their Influence on Satellite Estimates of Primary Production. ASLO, Honolulu, Hawaii, February 2002.
- Mitchell, B.G., M. Kahru, J. Wieland, and H. Wang, J.C. Chen, N.W. Man, and Y.S. Suh. (2002c) Case 2 Optical relationships for East Asian marginal seas. *Ocean Optics XVI Conference*. Santa Fe, New Mexico, November 18-22, 2002.
- O'Reilly, J.E., S. Maritorena, B.G. Mitchell, D.A. Siegel, K.L. Carder, S.A. Garver, M. Kahru and C. McClain (1998) Ocean color chlorophyll algorithms for SeaWiFS. *Journal of Geophysical Research.* 103(C11): 24,937-24,953
- O'Reilly, J.E., S. Maritorena, D.A. Siegel, M.C. O'Brien, D.A. Toole, B.G. Mitchell, M. Kahru, et al. (2000) Ocean color chlorophyll a algorithms for SeaWiFS, OC2 and OC4: Version 4. In: NASA, *SeaWiFS Postlaunch Calibration and Validation Analyses*.
- Reynolds, R.A., D. Stramski and B.G. Mitchell (2001) A chlorophyll-dependent semianalytical reflectance model from derived from field measurements of absorption and back scattering coefficients within the Southern Ocean. *Journal of Geophysical Research.* 106(C4): 7125-7138
- Stramska, M., D. Stramski, B.G. Mitchell and C.D. Mobley (2000) Estimation of the absorption and backscattering coefficients from in-water radiometric measurements. *Limnology and Oceanography.* 45(3): 628-641

## Figure Captions

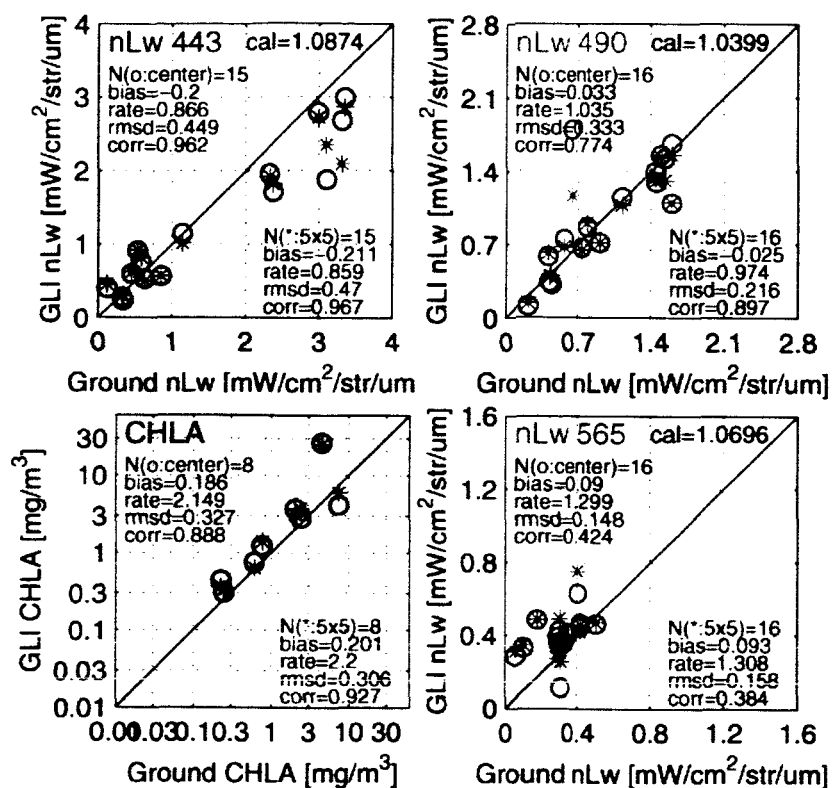
**Figure 1.** Global distribution of bio-optical stations accomplished in the past 5 years by the Scripps Photobiology Group (SPG). All stations include spectral reflectance and fluorometric chlorophyll. Most include particle and soluble absorption and HPLC pigments. For many cruises since 1997 we have deployed Hydrosat backscatter and AC9 absorption and attenuation meters to better understand the variables that govern remote sensing reflectance.

**Figure 2.** Validation of GLI water-leaving radiances (nLw) at 443, 490 and 565 nm, and of the empirical OC4-GLI chlorophyll algorithm during CalCOFI 0304 cruise. The *in situ* nLw were measured with the PRR-800. The GLI match-ups were estimated both as the value of the nearest pixel (o) and as average for a 5 x 5 pixel area (\*) centered at the nearest pixel. The chl-a match-ups show very good performance of the OC4-GLI algorithm. The only station with a significant difference was a near-shore station with expected problems like small-scale spatial variability, terrestrial aerosols and stray light.

**Figure 3.** Validation of SeaWiFS water-leaving radiance spectra with three match-ups within a 3-hour time lag during the CalCOFI 0304 cruise. At each station two casts of PRR-800 were made to get *in situ* nLw spectra between 313 and 700 nm (continuous line with X). The SeaWiFS nLw spectra were estimated with SeaDAS version 4.4 and the default options. While at longer wavelengths the SeaWiFS-derived nLw values are within the in-station variability range of *in situ* values; at 412 and even at 443 nm SeaWiFS is still under-predicting the *in situ* nLw. It should be noted that all three match-ups were near-shore and had high to very high chl-a concentration (7.45, 2.23 and 13.74 mg m<sup>-3</sup>). At near-shore stations the discrepancies may be caused by small-scale spatial variability, terrestrial aerosols and stray light. In fact, the large small-scale variability in *in situ* nLw is shown at the bottom panel.

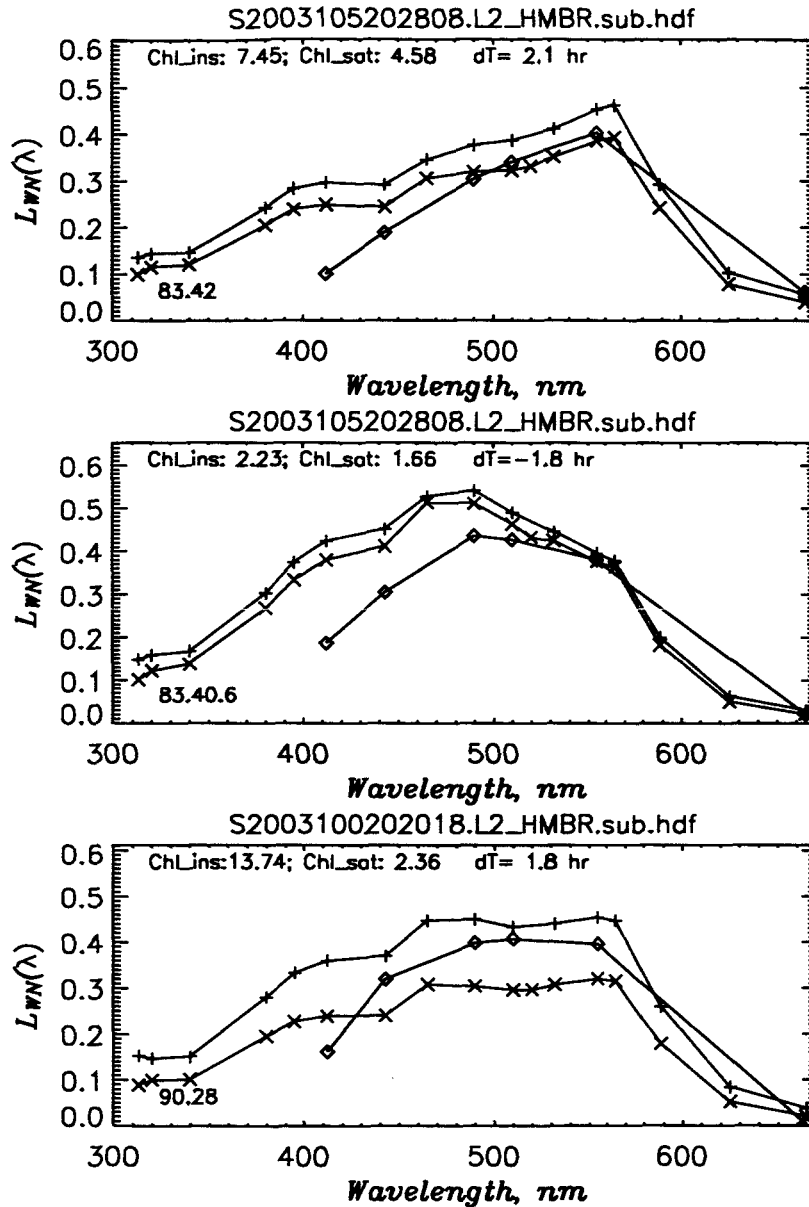


**Figure 1.** Global distribution of bio-optical stations accomplished in the past 5 years by the Scripps Photobiology Group (SPG). All stations include spectral reflectance and fluorometric chlorophyll. Most include particle and soluble absorption and HPLC pigments. For many cruises since 1997 we have deployed Hydroscat backscatter and AC9 absorption and attenuation meters to better understand the variables that govern remote sensing reflectance.



**Figure 2.** Validation of GLI water-leaving radiances (nLw) at 443, 490 and 565 nm, and of the empirical OC4-GLI chlorophyll algorithm during CalCOFI 0304 cruise. The *in situ* nLw were measured with the PRR-800. The GLI match-ups were estimated both as the value of the nearest pixel (o) and as average for a 5 x 5 pixel area (\*) centered at the nearest pixel. The chl-a match-ups show very good performance of the OC4-GLI algorithm. The only station with a significant difference was a near-shore station with expected problems like small-scale spatial variability, terrestrial aerosols and stray light.





**Figure 3.** Validation of SeaWiFS water-leaving radiance spectra with three match-ups within a 3-hour time lag during the CalCOFI 0304 cruise. At each station two casts of PRR-800 were made to get *in situ* nLw spectra between 313 and 700 nm (continuous line with X). The SeaWiFS nLw spectra were estimated with SeaDAS version 4.4 and the default options. While at longer wavelengths the SeaWiFS-derived nLw values are within the in-station variability range of *in situ* values, at 412 and even at 443 nm SeaWiFS is still under-predicting the *in situ* nLw. It should be noted that all three match-ups were near-shore and had high to very high chl-a concentration (7.45, 2.23 and 13.74 mg m<sup>-3</sup>). At near-shore stations the discrepancies may be caused by small-scale spatial variability, terrestrial aerosols and stray light. In fact, the large small-scale variability in *in situ* nLw is shown at the bottom panel.

# Year End Technical Memorandum 2002

## Bio-optical measurement and modeling of the California Current and Southern Oceans

B. Greg Mitchell, Principal Investigator  
Scripps Institution of Oceanography  
University of California San Diego  
La Jolla, CA 92093-0218  
Email: gtmitchell@ucsd.edu, Phone: (858) 534-2687

Contract number: NAS5-01002

### ***Introduction***

This SIMBIOS project contract has supported *in situ* ocean optical observations in the California Current, and in the north Pacific, Southern and Indian Oceans. Our principal goals are to validate standard or experimental ocean color products through detailed bio-optical and biogeochemical measurements, and to combine ocean optical observations with modeling to contribute to satellite vicarious radiometric calibration and algorithm development. In collaboration with major oceanographic ship-based observation programs (CalCOFI, JGOFS, AMLR, INDOEX, and ACE Asia) our SIMBIOS effort has resulted in data from diverse bio-optical provinces. For these global deployments we generate a methodologically consistent data set encompassing a wide-range of oceanic conditions. We have initiated several collaborations with scientists in East Asian countries to study the complex Case-2 waters of their marginal seas. Global data collected in recent years are routinely evaluated relative to our CalCOFI time-series. The combined database we have assembled now comprises more than 1000 stations and includes observations for the clearest oligotrophic waters, highly eutrophic blooms, red-tides and coastal Case-2 conditions. The data has been used to validate water-leaving radiance estimated with SeaWiFS as well as bio-optical algorithms for chlorophyll pigments. The comprehensive data is utilized for development of standard and experimental algorithms.

### ***Research Methods and Data***

We continue to participate on CalCOFI cruises to the California Current System (CCS) for which we have an 8-year time-series. This region experiences a large dynamic range of coastal and open ocean trophic structure and has experienced strong interannual forcing associated with the El Niño – La Niña cycle from 1997-2000 (Kahru and Mitchell, 2000; Kahru and Mitchell, 2002). CalCOFI data provides an excellent reference for evaluating our other global data sets (O'Reilly et al. 1998; Mitchell et al. 2002b, 2002c).

During the second year of our contract, we participated in 3 CalCOFI cruises, two collaborative cruises to the Southern Ocean (AMLR and SOFEX), and received data from colleagues in Korea and Hong Kong for 3 East Asian coastal cruises. The global distribution of our present data set is shown in Figure 1. On most cruises, an integrated underwater profiling system was used to collect optical data and to characterize the water column. The system included an underwater radiometer (Biospherical Instruments MER-2040 or MER-2048) measuring depth, downwelling spectral irradiance ( $E_d$ ) and upwelling radiance ( $L_u$ ) in 13 spectral bands. A MER-2041 deck-mounted reference radiometer (Biospherical Instruments) provided simultaneous measurements of above-surface downwelling irradiance. Details of the profiling procedures, characterization and calibration of the radiometers, data processing and quality control are described in Mitchell and Kahru (1998). The underwater radiometer was also interfaced with 25 cm transmissometers (SeaTech or WetLabs), a fluorometer, and SeaBird conductivity and temperature probes. When available, additional instrumentation integrated onto the profiling package included AC9 absorption and attenuation meters (WetLabs Inc.), and a Hydrosat-6 backscattering meter (HobiLabs). For two AMLR, ACE Asia and recent CalCOFI cruises we deployed our new Biospherical Instruments PRR-800 freefall radiometer that included 19 channels of surface irradiance (312-865 nm) and three geometries of underwater

radiometry ( $L_u$ ,  $E_u$ ,  $E_d$ ) from 312 to 700 nm. We have shown that measuring these three radiometric geometries with our MER 2048 allowed us to retrieve backscatter and absorption coefficients (Stramska et al., 2000). Our colleagues in Hong Kong and Korea use PRR-800 profilers and collect samples for chlorophyll and absorption with methods consistent with ours.

At *in situ* optical stations discrete water samples were collected from a CTD-Rosette immediately before or after each profile for additional optical and biogeochemical analyses. Pigment concentrations were determined fluorometrically and with HPLC. All HPLC samples acquired in the past year have been submitted to San Diego State University for analysis under a separate SIMBIOS contract. Spectral absorption coefficients (300-800 nm) of particulate material were estimated by scanning particles concentrated onto Whatman GF/F filters (Mitchell, 1990) in a dual-beam spectrophotometer (Varian Cary 1). Absorption of soluble material was measured in 10 cm cuvettes after filtering seawater samples through 0.2  $\mu$ m pore size polycarbonate filters. Absorption methods are described in more detail in Mitchell et al. (2002a). For some cruises we collected measurements of other optical and phytoplankton properties including photosynthesis, particulate organic matter (carbon and nitrogen), phycoerythrin pigment, and size distribution using flow cytometry and a Coulter Multi-sizer.

For most of our field work in association with CalCOFI and AMLR we submit all data directly to NASA SIMBIOS including supporting CTD and water bottle information. For the collaborations with Asian colleagues, we process their optical data and with their permission we will submit some of the Asian data to SIMBIOS in 2003. On the SOFEX cruise to the Southern Ocean we did not deploy a profiling radiometer, but we collected data for particle absorption; other SOFEX PIs collected samples for fluorometric chlorophyll and HPLC pigments. Our absorption data from SOFEX will be submitted to SIMBIOS and we will request approval to submit the pigment data.

## Research Results

Remote sensing reflectance ( $R_{rs}$ ) derived from the in-water measurements, defined as the ratio of upwelling radiance ( $L_u$ ) and downwelling irradiance ( $E_d$ ), is closely related to the normalized water-leaving radiance ( $L_{wn}$ ) product of satellite ocean color data.  $R_{rs}(\lambda)$  in Case-1 waters is well correlated to chl-a. As chl-a increases,  $R_{rs}$  generally decreases for SeaWiFS wavelengths 412, 443, 490, 510 nm due to increased absorption, but increases at SeaWiFS wavelength 555 and 665 nm due to increased backscatter [Mitchell and Kahru, 1998; O'Reilly et al., 1998]. To explore issues with Case-2 waters we have collaborated with colleagues in Korea (NFRDI), and Hong Kong (HKUST) to assemble a large regional data set from the East China Sea, South China Sea and coastal waters of Eastern Asia. Relationships between  $R_{rs}$  and chl-a for HKUST and NFRDI data can be both lower and higher than the Case-1 (CalCOFI) relationships, depending on whether absorption or scattering is the dominant process (data not shown).

Typical ocean color algorithms take ratios of reflectance for different spectral bands. The standard SeaWiFS chl-a algorithm is currently OC4v4 [O'Reilly et al., 1998; O'Reilly et al., 2000]. In Figure 2 we show 2-band  $R_{rs}$  ratios from our *in situ* data for combinations of SeaWiFS channels plotted versus surface chl-a for our Asian and CalCOFI data sets. CalCOFI data are a good reference data set since it covers a large range of chl-a, was acquired with very consistent methodology, and comprises approximately 25% of the data used for development of the SeaWiFS OC4v4 algorithm (O'Reilly et al., 2000). Kahru and Mitchell (1999; 2001) have shown that the chl-a retrieved by satellite in the CalCOFI region is in good agreement with our ship data when computed with our regional algorithm or NASA's OC4v4. A large portion of the variability attributed to backscatter cancels when taking ratios of different bands but the Case-2 data from the HKUST and NFRDI data tend to fall below the reference CalCOFI data due to enhanced absorption while the ACE Asia and Japan/East Sea data sets are very similar to CalCOFI (Figure 2).

Application of the standard NASA OC4 Case-1 algorithm, and our similar California Current algorithm for HKUST *in situ* data, produces significant scatter and bias (Figure 3). Both the standard SeaWiFS chl-a algorithm (OC4v4) and our similar Case-1 algorithm (OC4-SPG) switch to the maximum band ratio (the maximum of either  $R_{rs}$  or  $L_{wn}$  at 443, 490 or 510 nm divided by  $R_{rs}$  or  $L_{wn}$  at 555 nm) to calculate chl-a. In Case-1 waters most bio-optical variables including absorption are well correlated with chl-a which is why simple empirical band ratio algorithms work well for Case-1 waters. In the Hong Kong waters (Figure 4A) the lower range of the particulate

absorption ( $a_p$ ) data approaches the Case-1 CalCOFI relationship of  $a_p$  versus chl-a but the majority of the samples have significantly higher absorption at the respective chl-a level. This “excess” particulate absorption, attributed to suspended organic sediments, is especially dominant at low chl-a and causes  $a_p$  to be up to two orders of magnitude higher than would be predicted from chl-a concentration using typical Case-1 models. In Hong Kong waters the magnitude of CDOM absorption is approximately 2-3 times higher at low chl-a and up to an order of magnitude higher at high chl-a than our CalCOFI reference data (Figure 4B).

Due to the high concentration of CDOM and other absorbing substances both algorithms overestimate chl-a in the turbid coastal waters of Hong Kong up to an order of magnitude. Some of the Hong Kong stations with low chl-a that were collected off the shelf break are very similar to Case-1 relationships. One dramatic difference between the East Asian data and our CalCOFI data set is the very high variance in the relationship between particle absorption and chl-a (Figure 4A). Soluble absorption in the region also tends to be higher than for CalCOFI (Figure 4B). Bias in the Asian coastal data compared to CalCOFI in the plots of reflectance ratios vs chl-a (Figure 2) are consistent with higher absorption that is likely due both to detrital and soluble absorption. These issues will continue to complicate remote sensing retrieval in Case-2 waters using passive reflectance in the blue-green region. This recently merged data set is being used to evaluate Case-2 algorithms in collaboration with our Asian colleagues (Kahru et al., 2002; Mitchell et al. 2002c).

Processing SeaWiFS data with SeaDAS (corresponding to global SeaWiFS re-processing v4) still results in significant underestimates of  $L_{wn}$  at 412 and 443 for some of our Case-1 water match-ups with high resolution HRPT data. Figure 5 shows spectral  $L_{wn}$  for SeaWiFS retrieval using SeaDAS v3 and v4 compared to our water leaving radiances computed for our freefall PRR-800 radiometer. All three stations were in Case-1 water types with moderate chl-a concentrations ( $0.3 - 0.8 \text{ mg chl-a m}^{-3}$ ). The offshore station between Hawaii and Japan had reasonable retrieval of spectral  $L_{wn}$  (Figure 5A) but the 412 nm retrieval is still sufficiently low that it would create errors in attempts to retrieve CDOM accurately. The two stations closer to Asia were very close to each other and were within the Kuroshio intrusion between Japan and Korea (Figures 5B and 5C). Both stations close to the coast had severe underestimates in  $L_{wn}$  for the 412 and 443 channels and more modest underestimates at 490 nm. We believe the errors in  $L_{wn}$  retrieval between SeaWiFS and our PRR-800 in situ radiometer for the East Asian images are caused by errors in the aerosol models in the atmospheric correction for SeaWiFS for atmospheres that have significant terrestrial or anthropogenic aerosols. The new version of SeaDAS (corresponding to the global v4) released in summer of 2002 continues to severely under-predict  $L_{wn}$  for vast expanses of the ocean apparently due to inaccurate aerosols models. However, the chl-a estimates, even under the turbid absorbing aerosols for these ACE Asia stations, is surprisingly good due to the use of band-ratio empirical algorithms. Continued research on atmospheric aerosols is required to improve the accuracy of  $L_{wn}$  if we are to be able to apply multi-wavelength bio-optical retrieval algorithms that require accurate estimates of  $L_{wn}$  at 412 and 443 (e.g. Garver and Siegel, 1997; Carder et al., 1999). We collaborated with ACE Asia participants in evaluation of issues for atmospheric correction in waters of the western Pacific and marginal seas near Asia (Li et al., in press) and we will collaborate in the next year on implementing alternative atmospheric correction and in situ bio-optical algorithms and their validation.

### ***Future Plans***

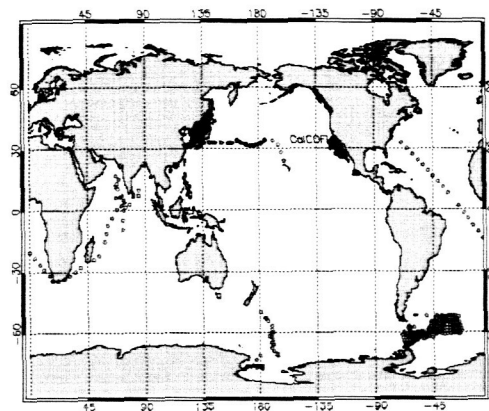
We will continue our approach of acquiring detailed data sets at the global scale for ocean color satellite validation and algorithm development. CalCOFI will continue as our core field program and we will execute one detailed CalCOFI cruise during April 2003 with other SIMBIOS PIs and with members of the SIMBIOS Project. We are advising the CalCOFI program on concepts for a permanent optics program to be integrated into their routine CTD profiling. A close cooperation has been initiated with the IMECOCAL program off Baja California that is coordinated by scientists from CICESE in Ensenada, Mexico. We have trained a student from Peru who will deploy our optical instruments on Peru coastal cruises during 2003. The Southern Ocean and East Asian marginal seas will continue to be a high priority since it is evident that standard algorithms for chl-a do not perform well in these regions (Mitchell and Holm-Hansen, 1991; Mitchell, 1992; Mitchell et al., 2002b; Reynolds et al., 2001; Kahru et al., 2002). Modeling efforts will continue to improve our understanding of regional bio-optical properties and their relationship to biogeochemical parameters (e.g. Stramska et al., 2000; Reynolds et al., 2001; Loisel et al., 2001). The models and data will contribute to development of advanced algorithms and parameterizations for semi-analytical inverse models for the retrieval of inherent optical properties and biogeochemical properties besides

chl-a. In particular we will focus on methods to retrieve CDOM, particulate organic carbon and particle size distributions simultaneously with chl-a using our global data sets and detailed water sample analyses.

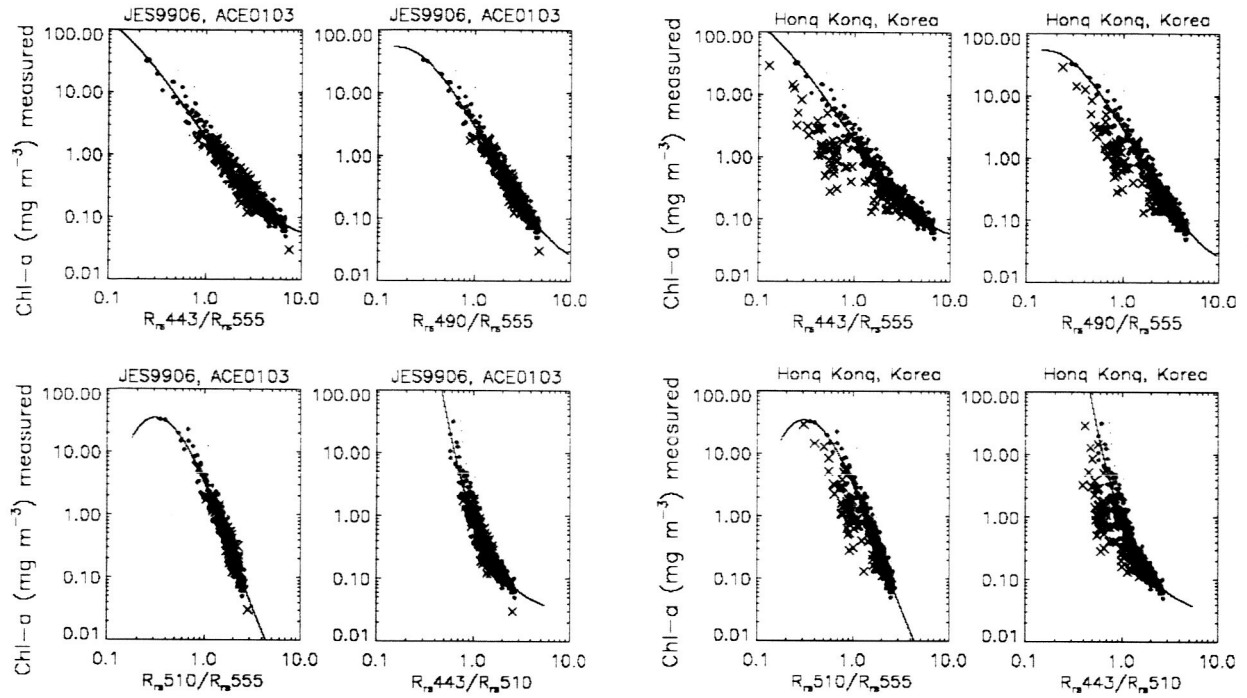
## References

- Carder, K.L., F.R. Chen, Z.P. Lee and S.K. Hawes (1999) Semianalytic moderate-resolution imaging spectrometer algorithms for chlorophyll a and absorption with bio-optical domains based on nitrate-depletion temperatures. *Journal of Geophysical Research*. 104(C3): 5,403-5,421
- Garver, S.A. and D.A. Siegel (1997) Inherent Optical Property Inversion of Ocean Color Spectra and its Biogeochemical Interpretation: 1. Time series from the Sargasso Sea. *Journal of Geophysical Research*. 102(C8): 18,607-18,625
- Kahru, M. and B.G. Mitchell (1999) Empirical chlorophyll algorithm and preliminary SeaWiFS validation for the California Current. *International Journal of Remote Sensing*. 20(17): 3,423-3,430
- Kahru, M. and B.G. Mitchell (2000) Influence of the 1997-98 El Niño on the surface chlorophyll in the California Current. *Geophysical Research Letters*. 27(18): 2,937-2,940
- Kahru, M. and B.G. Mitchell (2001) Seasonal and non-seasonal variability of satellite-derived chlorophyll and colored dissolved organic matter concentration in the California Current. *Journal of Geophysical Research*. 106(C2): 2517-2529
- Kahru, M., B.G. Mitchell, J. Wieland, J.C. Chen, N.W. Man, Y.S. Suh, M. Stramska, and D. Stramski (2002) Evaluation of Satellite Ocean Color Algorithms for East Asian Marginal Seas. ASLO, Honolulu, Hawaii, February 2002.
- Kahru, M. and B.G. Mitchell (2002) Influence of El Niño – La Niña cycle on satellite-derived primary production in the California current. *Geophysical Research Letters*, 29(9), doi: 10.1029/2002GL014963
- Li, L.-P., H. Fukushima, R. Frouin, B.G. Mitchell, M. -X. He, I. Uno, T. Takamura, and S. Ohta (In Press) Influence of sub-micron absorptive aerosol on SeaWiFS-derived marine reflectance during ACE-Asia. *Journal of Geophysical Research – Atmospheres*.
- Loisel, H., D. Stramski, B.G. Mitchell, F. Fell, V. Fournier-Sicre, B. Lemasle, and M. Babin. (2001) Comparison of the ocean inherent optical properties obtained from measurements and inverse modeling. *Applied Optics*. 40(15): 2384-2397
- Mitchell, B.G. (1990) Algorithms for determining the absorption coefficient of aquatic particulates using the quantitative filter technique (QFT). In: Spinrad, R., ed., *Ocean Optics X*, Bellingham, Washington, SPIE, pp. 137-148
- Mitchell, B.G. (1992) Predictive bio-optical relationships for polar oceans and marginal ice zones. *Journal of Marine Systems*. 3: 91-105
- Mitchell, B.G. and M. Kahru (1998) Algorithms for SeaWiFS standard products developed with the CalCOFI bio-optical data set. *Cal.Coop.Ocean.Fish.Invest.R.* 39: 133-147
- Mitchell, B.G. and O. Holm-Hansen (1991) Bio-optical properties of Antarctic Peninsula waters: Differentiation from temperate ocean models. *Deep-Sea Research I*. 38(8/9): 1,009-1,028
- Mitchell B. G., M. Kahru, J. Wieland and M. Stramska (2002a) Determination of spectral absorption coefficients of particles, dissolved material and phytoplankton for discrete water samples. In: Fargion, G.S. and J.L. Mueller, Eds. Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, NASA Technical Memorandum 2002-210004/Rev 3-Vol 2, Chapter 15, P. 231-257.**
- Mitchell, B.G., M. Kahru, R. Reynolds, J. Wieland, D. Stramski, C. Hewes, and O. Holm-Hansen (2002b) Chlorophyll-a Ocean Color Algorithms for the Southern Ocean and their Influence on Satellite Estimates of Primary Production. ASLO, Honolulu, Hawaii, February 2002.**
- Mitchell, B.G., M. Kahru, J. Wieland, and H. Wang, J.C. Chen, N.W. Man, and Y.S. Suh. (2002c) Case 2 Optical relationships for East Asian marginal seas. *Ocean Optics XVI Conference*. Santa Fe, New Mexico, November 18–22, 2002.
- O'Reilly, J.E., S. Maritorena, B.G. Mitchell, D.A. Siegel, K.L. Carder, S.A. Garver, M. Kahru and C. McClain (1998) Ocean color chlorophyll algorithms for SeaWiFS. *Journal of Geophysical Research*. 103(C11): 24,937-24,953

- O'Reilly, J.E., S. Maritorena, D.A. Siegel, M.C. O'Brien, D.A. Toole, B.G. Mitchell, M. Kahru, et al. (2000) Ocean color chlorophyll a algorithms for SeaWiFS, OC2 and OC4: Version 4. In: NASA, SeaWiFS Postlaunch Calibration and Validation Analyses.
- Reynolds, R.A., D. Stramski and B.G. Mitchell (2001) A chlorophyll-dependent semianalytical reflectance model from derived from field measurements of absorption and back scattering coefficients within the Southern Ocean. *Journal of Geophysical Research*. 106(C4): 7125-7138
- Stramska, M., D. Stramski, B.G. Mitchell and C.D. Mobley (2000) Estimation of the absorption and backscattering coefficients from in-water radiometric measurements. *Limnology and Oceanography*. 45(3): 628-641

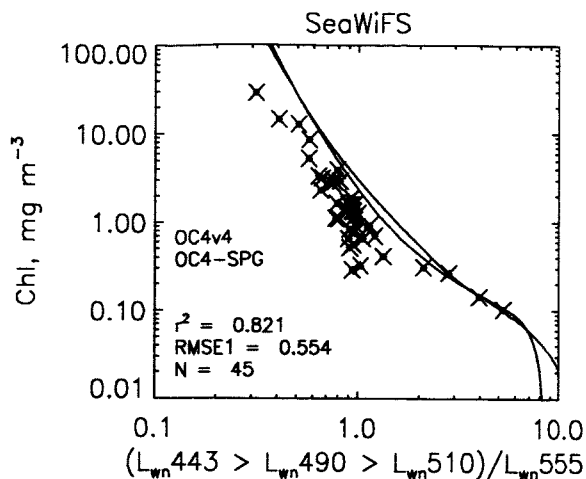


**Figure 1.** Global distribution of bio-optical stations accomplished in the past 5 years by the Scripps Photobiology Group (SPG). All stations include spectral reflectance and fluorometric chlorophyll. Most include particle and soluble absorption and HPLC pigments. For many cruises since 1997 we have deployed Hydroscat backscatter and AC9 absorption and attenuation meters to better understand the variables that govern remote sensing reflectance.

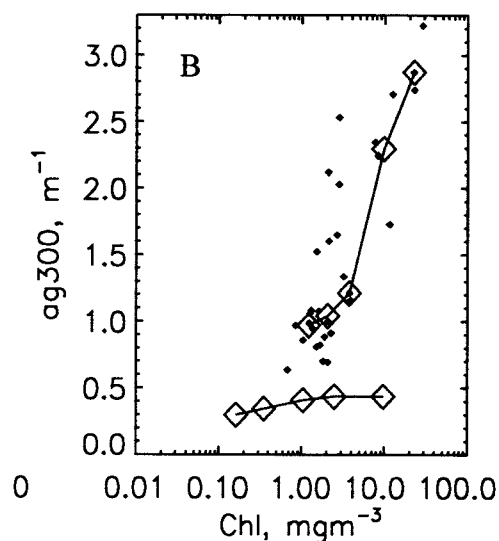
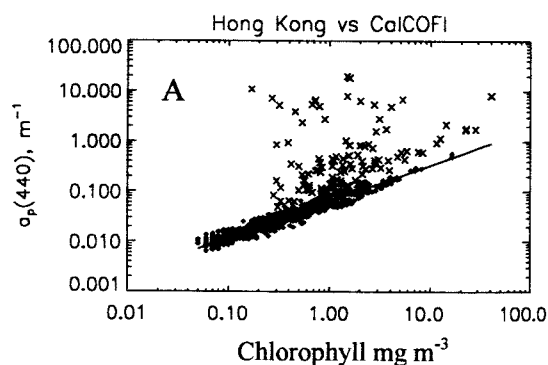


**Figure 2.** Surface reflectance ratios of SeaWiFS bands for *in situ* data. Blue symbols are from our CalCOFI reference set, red symbols from cruises to East Asian waters summarized in Figure 1. The set of ratios on the left contrast CalCOFI with our Japan / East Sea and ACE-Asia cruises that consisted primarily of Case-1 waters. The set of ratios on the right contrast our CalCOFI data with Hong Kong and Korean cruises in the East China and South China Seas where the majority of the stations were Case-2.

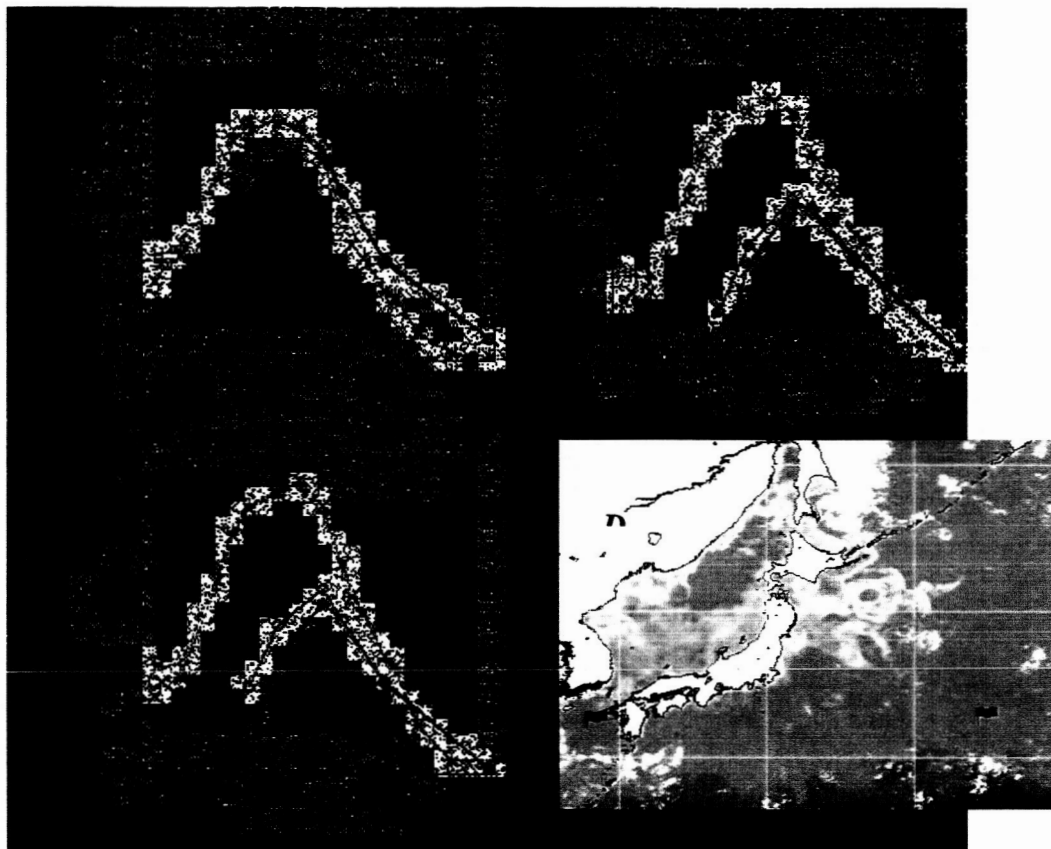




**Figure 3.** Comparison of HKUST data to NASA's OC4 and our similar algorithm (OC4-SPG). For most of the HKUST data, standard algorithms overestimate chl-a by 3-10x.



**Figure 4.** A. Absorption coefficient of particulate material at 440 nm as a function of chl-*a* for CalCOFI (black symbols) and Hong Kong samples (red x). B. Absorption coefficient of soluble material (CDOM) at 300 nm as a function of chl-*a* for CalCOFI (blue diamonds and the blue line are median values) and Hong Kong dataset (black symbols are discrete measurements, red line is the best fit). Both particle and soluble absorption for the HKUST cruises are much higher per unit chl-*a* than we find in Case-1 waters of CalCOFI. This increased absorption leads to the overestimates of chl-*a* using standard ocean color algorithms as shown in Figure 3.



**Figure 5.** Lwn matchups between ACE Asia *in situ* radiometry (x) and SeaWiFS (SeaDAS v3,  $\diamond$ ; SeaDAS v4,  $\diamond$ ) in the open north Pacific (A; 32.749 N, 154.929 E), the other two were very near to each other within the Kuroshio intrusion between Japan and Korea (B; 32.420 N, 128.538 E; C, 32.523 N, 128.410 E). (Note: the SeaDAS version corresponds to the global reprocessing v3 and v4). The SeaWiFS chl-a composite image for April (D) indicates the approximate location of these stations with two red flags. All three had moderate chl-a concentrations and were Case-1 waters. The chl-a determined by HPLC and the global re-processing v3 and v4 estimates are indicated on each Lwn spectral plot.

## **Year End Technical Memorandum 2001**

### **Bio-Optical measurement and modeling of the California Current and Southern Oceans**

B. Greg Mitchell, Principal Investigator  
Scripps Institution of Oceanography  
University of California San Diego  
La Jolla, CA 92093-0218  
Email: gtmitchell@ucsd.edu, Phone: (858) 534-2687

Contract number: NAS5-01002

### ***Introduction***

This SIMBIOS project contract has supported in situ ocean optical observations in the California Current, and the north Pacific, Southern and Indian Oceans. Our principal goals are to validate standard or experimental ocean color products through detailed bio-optical and biogeochemical measurements, and to combine ocean optical observations with modeling to contribute to satellite vicarious radiometric calibration and algorithm development.

In collaboration with major oceanographic ship-based observation programs (CalCOFI, JGOFS, AMLR, INDOEX, and ACE Asia) our SIMBIOS effort has resulted in data from diverse bio-optical provinces. For these global deployments we generate a methodologically consistent data set encompassing a wide-range of oceanic conditions. We have initiated several collaborations with scientists in East Asian countries to study the complex Case 2 waters of their marginal seas. Global data collected in recent years have been integrated with our on-going CalCOFI time-series. The combined database we have assembled now comprises more than 800 stations and includes observations for the clearest oligotrophic waters, highly eutrophic blooms, red-tides and coastal case 2 conditions. The data has been used to validate water-leaving radiance estimated with SeaWiFS as well as bio-optical algorithms for chlorophyll pigments. The comprehensive data is utilized for development of standard and experimental algorithms.

### ***Research Methods and Data***

We continue to participate on CalCOFI cruises to the California Current System (CCS) for which we have an 8-year time-series. This region experiences a large dynamic range of coastal and open ocean trophic structure and has experienced strong interannual forcing associated with the El Niño – La Niña cycle from 1997-2000 (Kahru and Mitchell, 2000; Kahru and Mitchell, 2001a). CalCOFI data provides an excellent reference for evaluating our other global data sets (O'Reilly et al. 1998).

During the third year of our contract, we participated in 3 CalCOFI cruises, one cruise in collaboration with NOAA AMLR to the Southern Ocean, and the ACE Asia cruise to the northwest Pacific on NOAA R/V Ronald Brown. The global distribution of our present data set is shown in Figure 1. On most cruises, an integrated underwater profiling system was used to collect optical data and to characterize the water column. The system included an underwater radiometer (Biospherical Instruments MER-2040 or MER-2048) measuring depth, downwelling spectral irradiance ( $E_d$ ) and upwelling radiance ( $L_u$ ) in 13 spectral bands. A MER-2041 deck-mounted reference radiometer (Biospherical Instruments) provided simultaneous measurements of above-surface downwelling irradiance. Details of the profiling procedures, characterization and calibration of the radiometers, data processing and quality control are described in Mitchell and Kahru (1998). The underwater radiometer was also interfaced with 25 cm transmissometers (SeaTech or WetLabs), a fluorometer, and SeaBird conductivity and temperature probes. When available, additional instrumentation integrated onto the profiling package included AC9 absorption and attenuation meters (WetLabs Inc.), and a Hydrosat-6 backscattering meter (HobiLabs). For the AMLR and ACE Asia cruises in 2001 we deployed our new Biospherical Instruments PRR 800 free fall radiometer that included 19 channels of surface irradiance 312- 865 nm and three geometries of underwater radiometry ( $L_u$ ,  $E_u$ ,

E<sub>d</sub>) from 312-700 nm. We have shown that measuring these three radiometric geometries with our MER 2048 allowed us to retrieve backscatter and absorption coefficients (Stramska et al., 2000).

At in situ optical stations discrete water samples were collected from a CTD-Rosette immediately before or after each profile for additional optical and biogeochemical analyses. Pigment concentrations were determined fluorometrically and with HPLC. All HPLC samples acquired in the past year have been submitted to San Diego State University for analysis under a separate SIMBIOS contract. Spectral absorption coefficients (300-800 nm) of particulate material were estimated by scanning particles concentrated onto Whatman GF/F filters (Mitchell 1990) in a dual-beam spectrophotometer (Varian Cary 1). Absorption of soluble material was measured in 10 cm cuvettes after filtering seawater samples through 0.2  $\mu\text{m}$  pore size polycarbonate filters. Absorption methods are described in more detail in Mitchell et al. (2001a). For some cruises we collected measurements of other optical and phytoplankton properties including photosynthesis, particulate organic matter (carbon and nitrogen), phycoerythrin pigment, and size distribution using flow cytometry and a Coulter Multisizer.

## **Research Results**

Our normalized water leaving radiances ( $L_{\text{wn}}$ ) at SeaWiFS bands for global data, except Southern Ocean, are plotted against surface chl-a in Figure 2A. Data collected during these cruises represents approximately 25% of the data used for development of the SeaWiFS OC4v4 algorithm (O'Reilly et al., 2000). Kahru and Mitchell (1999; 2001a) have shown that the chl-a retrieved by satellite in the CalCOFI region is in good agreement with our ship data when computed with our regional algorithm or NASA's OC4v4. Southern Ocean results for in situ observations during JGOFS (1997-1998) and AMLR (2000-2001) indicate a strong deviation from NASA's OC4v4 algorithm relationship for chl-a in the range 0.1-2.0  $\text{mg m}^{-3}$  (Figure 2B). This region has been shown to have bio-optical algorithms that are different than low latitude regions such as CalCOFI (Mitchell and Holm-Hansen, 1991; Mitchell, 1992; Arrigo et al., 1998; Dierssen and Smith, 2000). We have developed a new Southern Ocean chl-a algorithm based on an OC4-type fit to the Southern Ocean data set (Figure 2B; Mitchell et al., 2001b). These results underscore the need for more data to serve as a basis for regional algorithms to improve estimates of chl-a from ocean color remote sensing. A global ocean color data processing scheme needs to be specified that can transition from low latitude to high latitude without arbitrary discontinuities. More data and advanced models are required to resolve issues regarding Southern Ocean bio-optical algorithms and to understand the causes of observed differentiation. For a better understanding, it is essential to determine not only reflectance and chlorophyll, but also inherent optical properties including absorption and backscattering as reported by Reynolds et al. (2001). Generally, there are few observations in the Southern Ocean, and even fewer with detailed observations including inherent optical properties. During our AMLR cruise in January 2002 we will deploy our Hydrosat backscatter meter and collect water samples for measurement of particle and soluble absorption, HPLC pigments and particle size distribution to extend our understanding of Southern Ocean algorithm issues.

Processing SeaWiFS data with SeaDAS v4.1 still results in significant underestimates of  $L_{\text{wn}}$  at 412 and 443 for some of our case 1 water match ups with high resolution HRPT data. Figure 3 shows spectral  $L_{\text{wn}}$  for two ACE Asia stations, both in Case 1 water types with moderate chl-a concentrations (0.3 – 0.5  $\text{mg chl-a m}^{-3}$ ). The offshore station between Hawaii and Japan had reasonable retrieval of spectral  $L_{\text{wn}}$  (Figure 3A) but the Kuroshio intrusion station between Japan and Korea did not (Figure 3B). We believe this difference is caused by errors in the aerosol models in the atmospheric correction for SeaWiFS for atmospheres that have significant terrestrial or anthropogenic aerosols. Continued research on atmospheric aerosols is required to improve the accuracy of  $L_{\text{wn}}$  if we are to be able to apply multi-wavelength bio-optical retrieval algorithms that require accurate estimates of  $L_{\text{wn}}$  at 412 and 443 (e.g. Garver and Siegel, 1997; Carder et al., 1999). Collaborations with aerosols chemists and atmospheric optics experts will be expanded in the next year using ACE Asia and INDOEX data sets.

With colleagues in Korea, China, Japan and Hong Kong we have assembled a large regional data set from the East China Sea, South China Sea and coastal waters of Eastern Asia. Figure 4 shows reflectance ratios for SeaWiFS bands plotted against chl-a for CalCOFI and Asian data sets. Where the Asian data deviate, it is usually toward a lower ratio compared to CalCOFI. One dramatic difference between the East Asian data and our CalCOFI data set is the very high variance in the relationship between particle absorption and chl-a (Figure 5). Soluble absorption in the region also tends to be higher than for CalCOFI (data not shown). The reflectance trends for Asian data (Figure

4) are consistent with higher absorption that is likely due both to detrital and soluble absorption. This recently merged data set is being used to evaluate Case 2 algorithms in collaboration with our Asian colleagues (Kahru et al., 2001b).

### ***Future Plans***

We will continue our approach of acquiring detailed data sets at the global scale for ocean color satellite validation and algorithm development. CalCOFI will continue as our core field program and we plan to complete one detailed CalCOFI cruise per year and 3 that have a minimal set of chl-a and reflectance data. We are advising the CalCOFI program on concepts for a permanent optics program to be integrated into their routine CTD profiling. A close cooperation has been initiated with the IMEMECOCAL program off Baja California that is coordinated by scientists from CICESE in Ensenada, Mexico. Data from their cruises starting in 1997 will be available to us in 2002. The Southern Ocean and East Asian marginal seas will continue to be a high priority since it is evident that standard algorithms for chl-a do not perform well in these regions. In January, 2002 we will participate in the NOAA AMLR cruise to the Southern Ocean. During 2002 we will organize a SIMBIOS workshop to address polar algorithm issues. Modeling efforts will continue to improve our understanding of regional bio-optical properties and their relationship to biogeochemical parameters (e.g. Stramska et al., 2000; Reynolds et al, 2001; Loisel et al., 2001). The models and data will contribute to development of advanced algorithms and parameterizations for semi-analytical inversion models for the retrieval of inherent optical properties and biogeochemical properties besides chl-a.

### ***References***

- Arrigo, K.R., D.H. Robinson, D.L. Worthen, B. Schieber and M.P. Lizotte (1998) Bio-optical properties of the southwestern Ross Sea. *Journal of Geophysical Research*. 103(C10): 21,683-21,695
- Carder, K.L., F.R. Chen, Z.P. Lee and S.K. Hawes (1999) Semianalytic moderate-resolution imaging spectrometer algorithms for chlorophyll a and absorption with bio-optical domains based on nitrate-depletion temperatures. *Journal of Geophysical Research*. 104(C3): 5,403-5,421
- Dierssen, H.M. and Smith, R.C. (2000) Bio-optical properties and remote sensing ocean color algorithms for Antarctic Peninsula waters, *Journal of Geophysical Research*, 105(C11): 26301-26312.
- Garver, S.A. and D.A. Siegel (1997) Inherent Optical Property Inversion of Ocean Color Spectra and its Biogeochemical Interpretation: 1. Time series from the Sargasso Sea. *Journal of Geophysical Research*. 102(C8): 18,607-18,625
- Kahru, M. and B.G. Mitchell (1999) Empirical chlorophyll algorithm and preliminary SeaWiFS validation for the California Current. *International Journal of Remote Sensing*, 20(17): 3,423-3,430
- Kahru, M. and B.G. Mitchell (2000) Influence of the 1997-98 El Niño on the surface chlorophyll in the California Current. *Geophysical Research Letters*. 27(18): 2,937-2,940
- Kahru, M. and B.G. Mitchell (2001a) Seasonal and non-seasonal variability of satellite-derived chlorophyll and colored dissolved organic matter concentration in the California Current. *Journal of Geophysical Research*. 106(C2): 2517-2529.
- Kahru, M., B. G. Mitchell, J. Wieland, J. C. Chen, N. W. Man, and Y. S. Suh (2001b) Validation of Ocean Color Algorithms in East Asian Marginal Seas. *American Geophysical Union Conference*. San Francisco. 10-14 December, 2001.
- Loisel, H. and D. Stramski (2000) Estimation of the inherent optical properties of natural waters from the irradiance attenuation coefficient and reflectance in the presence of Raman scattering. *Applied Optics*. 39(18): 3,001-3,011
- Mitchell, B.G. (1990) Algorithms for determining the absorption coefficient of aquatic particulates using the quantitative filter technique (QFT). In: Spinrad, R., ed., *Ocean Optics X*, Bellingham, Washington, SPIE, pp. 137-148
- Mitchell, B.G. (1992) Predictive bio-optical relationships for polar oceans and marginal ice zones. *Journal of Marine Systems*. 3: 91-105
- Mitchell, B.G. and M. Kahru (1998) Algorithms for SeaWiFS standard products developed with the CalCOFI bio-optical data set. *Cal.Coop.Ocean.Fish.Invest.R.* 39: 133-147

- Mitchell, B.G. and O. Holm-Hansen (1991) Bio-optical properties of Antarctic Peninsula waters: Differentiation from temperate ocean models. *Deep-Sea Research I*. 38(8/9): 1,009-1,028
- Mitchell B. G. , M. Kahru, J. Wieland and M. Stramska (2001a) Determination of spectral absorption coefficients of particles, dissolved material and phytoplankton for discrete water samples. In: NASA, Ocean Optics Protocols for Satellite Ocean Color Sensor Validation.
- Mitchell, B. G., M. Kahru, R. Reynolds, J. Wieland, D. Stramski, C. Hewes, O. Holm-Hansen (2001b) Evaluation of Chlorophyll-a Ocean Color Algorithms for the Southern Ocean. American Geophysical Union. San Francisco. 10-14 December, 2001.
- O'Reilly, J.E., S. Maritorena, B.G. Mitchell, D.A. Siegel, K.L. Carder, S.A. Garver, M. Kahru and C. McClain (1998) Ocean color chlorophyll algorithms for SeaWiFS. *Journal of Geophysical Research*. 103(C11): 24,937-24,953
- O'Reilly, J.E., S. Maritorena, D.A. Siegel, M.C. O'Brien, D.A. Toole, B.G. Mitchell, M. Kahru, et al. (2000) Ocean color chlorophyll a algorithms for SeaWiFS, OC2 and OC4: Version 4. In: NASA, SeaWiFS Postlaunch Calibration and Validation Analyses.
- Reynolds, R.A., D. Stramski and B.G. Mitchell (2001) A chlorophyll-dependent semianalytical reflectance model from derived from field measurements of absorption and back scattering coefficients within the Southern Ocean. *Journal of Geophysical Research*. 106(C4): 7125-7138.
- Siegel, D.A., M. Wang, S. Maritorena and W. Robinson (2000) Atmospheric correction of satellite ocean color imagery: The black pixel assumption. *Appl.Opt.* 39(21): 3,582-3,591
- Stramska, M., D. Stramski, B.G. Mitchell and C.D. Mobley (2000) Estimation of the absorption and backscattering coefficients from in-water radiometric measurements. *Limnology and Oceanography*. 45(3): 628-641

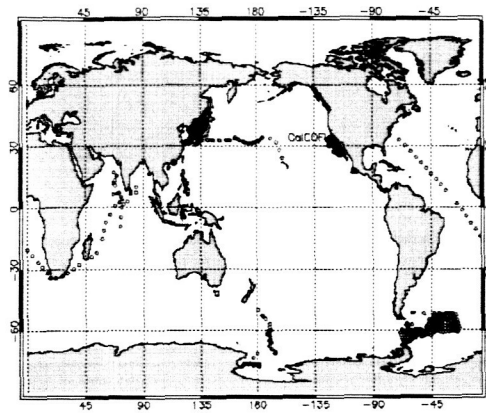


Figure 1. Global distribution of bio-optical stations accomplished in the past 5 years by the Scripps Photobiology Group (SPG). All stations include spectral reflectance and fluorometric chlorophyll. Most include particle and soluble absorption and HPLC pigments. For some CalCOFI and all international cruises since 1997 we have deployed Hydrosat backscatter and AC9 absorption and attenuation meters to better understand the variables that govern remote sensing reflectance.

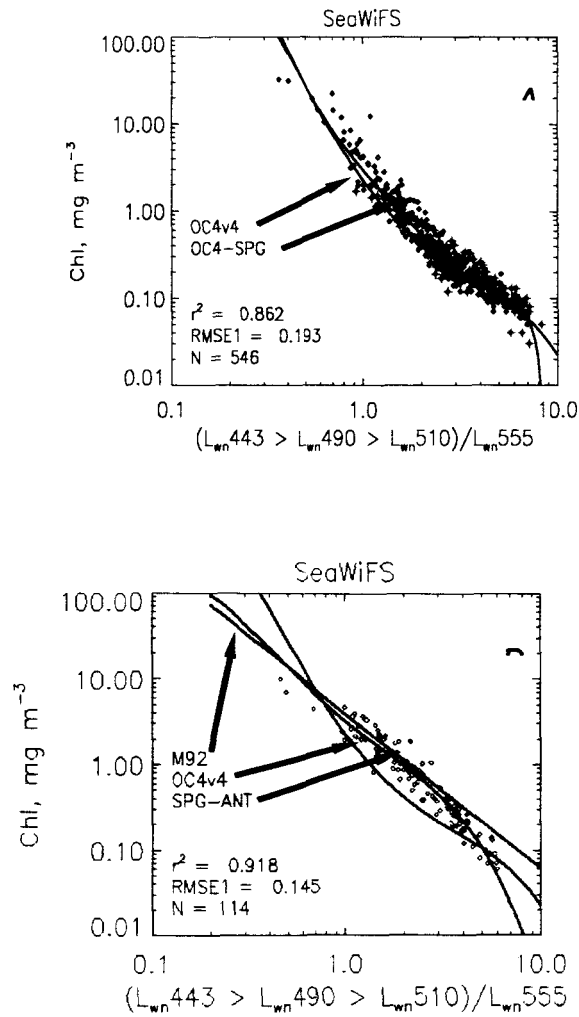


Figure 2. A. Maximum band ratio algorithms for the SPG Case 1 global data set excluding our Southern Ocean JGOFS and AMLR data.. These data comprise approximately 25% of NASA's SeaWiFS chl-a algorithm data set used by O'Reilly et al. (2000). The lines are fits for NASA's SeaWiFS OC4v4 and our OC4-type fit to the SPG data set. Minor differences between OC4v4 and OC4-SPG fit to our data are evident for chl-a between 0.3 – 3.0 mg m<sup>-3</sup>. B. Spectral reflectance band ratios plotted against chl-a for our Southern Ocean data set. The curved line through the data is our SPG-ANT relationship for the Southern Ocean and the curved line that does not fit the data is NASA's standard OC4v4 relationship. The linear line is the Mitchell (1992) Antarctic fit.



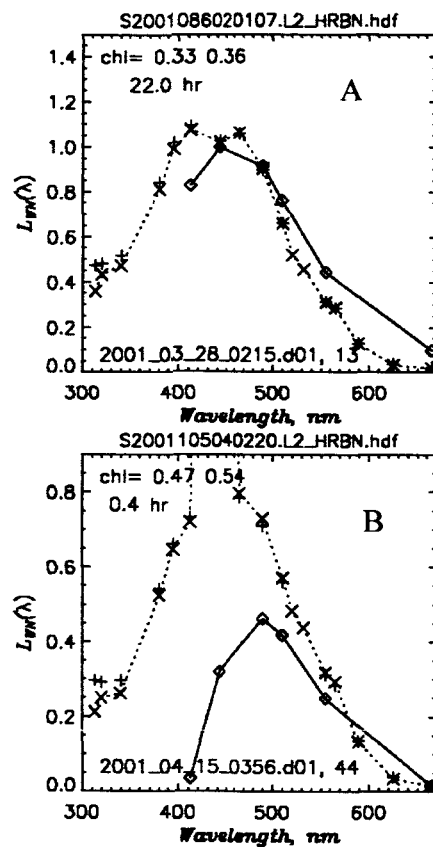


Figure 3. Lwn matchups between ACE Asia in situ radiometry (x) and SeaWiFS (◇) in the open north Pacific (A) and in the Kuroshio intrusion between Japan and Korea (B). Both had similar chl-a concentrations and were Case 1 waters. The large discrepancy in the east Asian region is attributed to errors in the aerosol models for SeaWiFS atmospheric corrections.

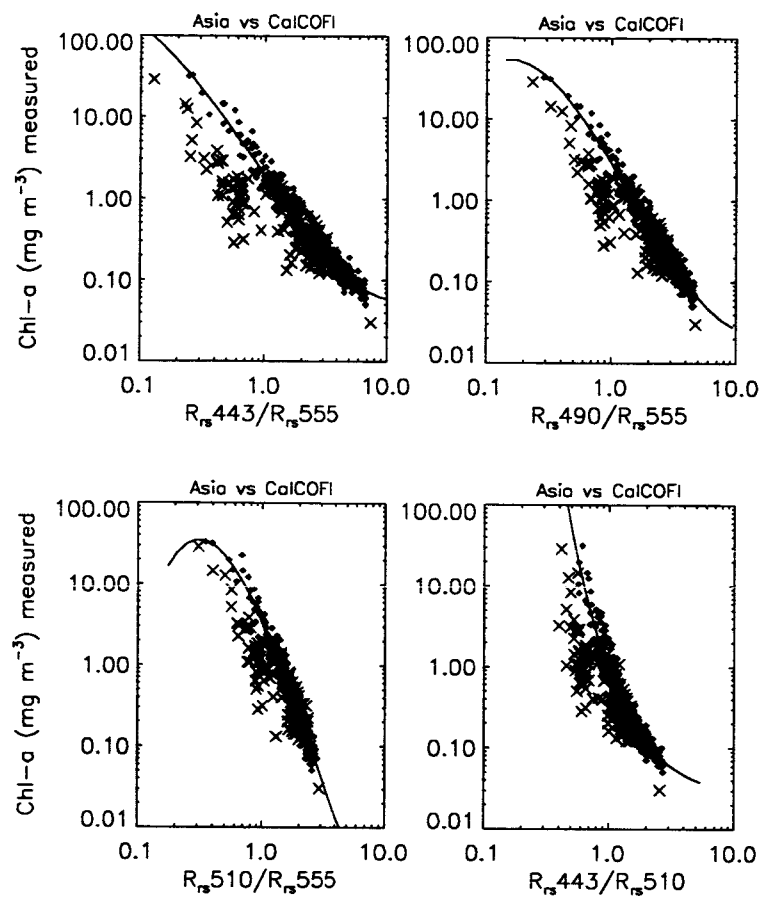


Figure 4. Scatter plots of ocean spectral reflectance ratios for various SeaWiFS bands plotted against chl-a for our CalCOFI (◊) and East Asian region (X) data sets. CalCOFI data have a coherent relationship, but some of the East Asian waters diverge due to complexity of Case 2 water constituents including detrital absorption, CDOM and mineral particles.

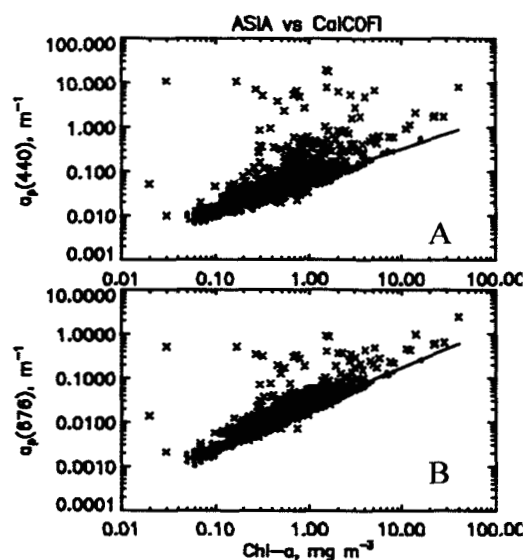


Figure 5. Spectral absorption by ocean particles plotted against chl-a for CalCOFI (•) and our East Asian data set (x). A. 440 nm; B. 676 nm. The line is a power fit to our CalCOFI data. Some of the Asian data is consistent with CalCOFI, but many near-coastal or shelf stations exhibit much higher absorption per unit chl-a than CalCOFI due to detrital pigments. This strong blue absorption will make retrieval of chl-a from passive reflectance in the blue very difficult in these waters since the dominant absorption will be from detritus and soluble material rather than chl-a and associated photosynthetic pigments.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b></p>					
1. REPORT DATE (DD-MM-YYYY)		2. REPORT TYPE		3. DATES COVERED (From - To)	
		Contractor Report		12/1/00 - 11/30/03	
4. TITLE AND SUBTITLE  Bio-Optical measurement and modeling of the California Current and Southern Oceans Final Report				5a. CONTRACT NUMBER	
				NAS5-01002	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)  B.Gregg Mitchell				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Goddard Space Flight Center Greenbelt, MD 20771				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSORING/MONITOR'S ACRONYM(S)  CR-2004-212759	
				11. SPONSORING/MONITORING REPORT NUMBER	
12. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified-Unlimited Report available from the NASA Center for Aerospace Information, 7121 Standard Drive, Hanover, MD 21076. (301)621-0390					
13. SUPPLEMENTARY NOTES  Scripps Institution of Oceanography, Univ. of CA San Diego, La Jolla, CA 92093-0218					
14. ABSTRACT  The SIMBIOS project's principal goals are to validate standard or experimental ocean color products through detailed bio-optical and biogeochemical measurements, and to combine ocean optical observations with modeling to contribute to satellite vicarious radiometric calibration and algorithm development.					
15. SUBJECT TERMS  SIMBIOS. California current, north Pacific ocean Indian Ocean					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19b. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Chuck McClain
				27	19b. TELEPHONE NUMBER (Include area code)